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Oberlaender

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(54) **DUAL ACCESS FOR SINGLE PORT CACHE**

(56) **References Cited**

(75) Inventor: **Klaus Oberlaender**, Neubiberg (DE)

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(73) Assignee: **Infineon Technologies AG**, Neubiberg (DE)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

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Primary Examiner — Gary Portka

(74) *Attorney, Agent, or Firm* — Eschweiler & Associates, LLC

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G06F 12/08 (2006.01)

(52) **U.S. Cl.**
CPC **G06F 12/0846** (2013.01); **G06F 12/0864** (2013.01); **Y02B 60/1225** (2013.01)

(58) **Field of Classification Search**

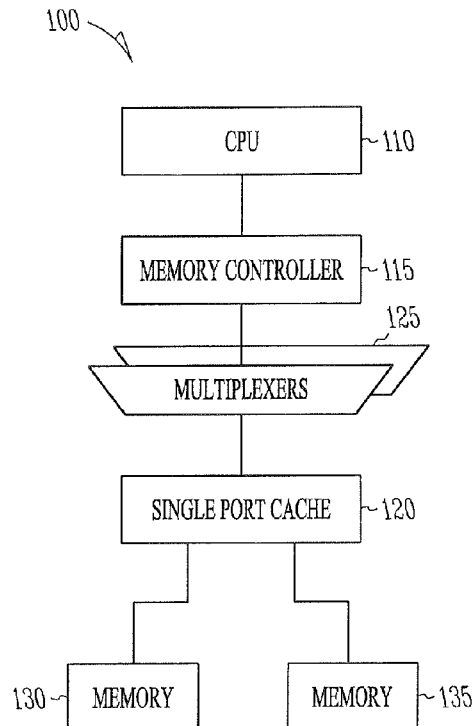
None

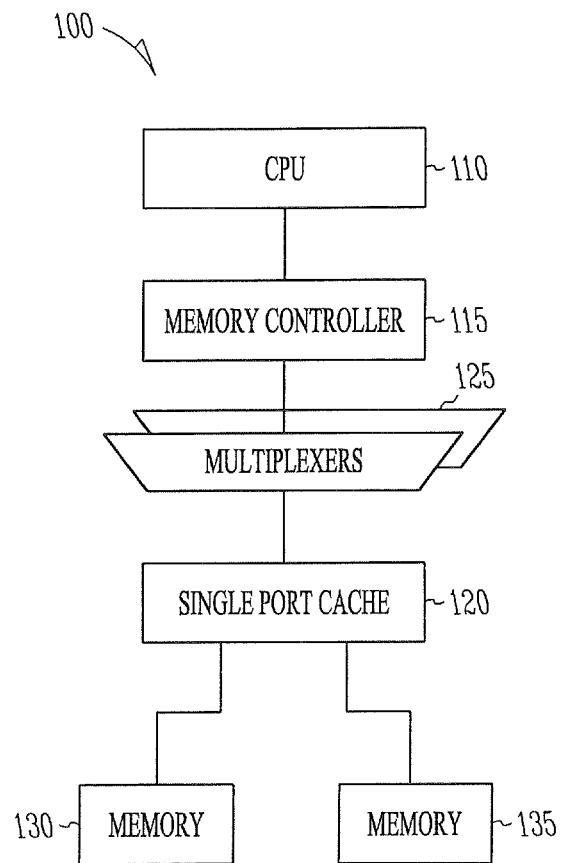
See application file for complete search history.

(57) **ABSTRACT**

A method and system for accessing a single port multi-way cache includes an address multiplexer that simultaneously addresses a set of data and a set of program instructions in the multi-way cache. Duplicate output way multiplexers respectively select data and program instructions read from the cache responsive to the address multiplexer.

19 Claims, 3 Drawing Sheets



*FIG. 1*

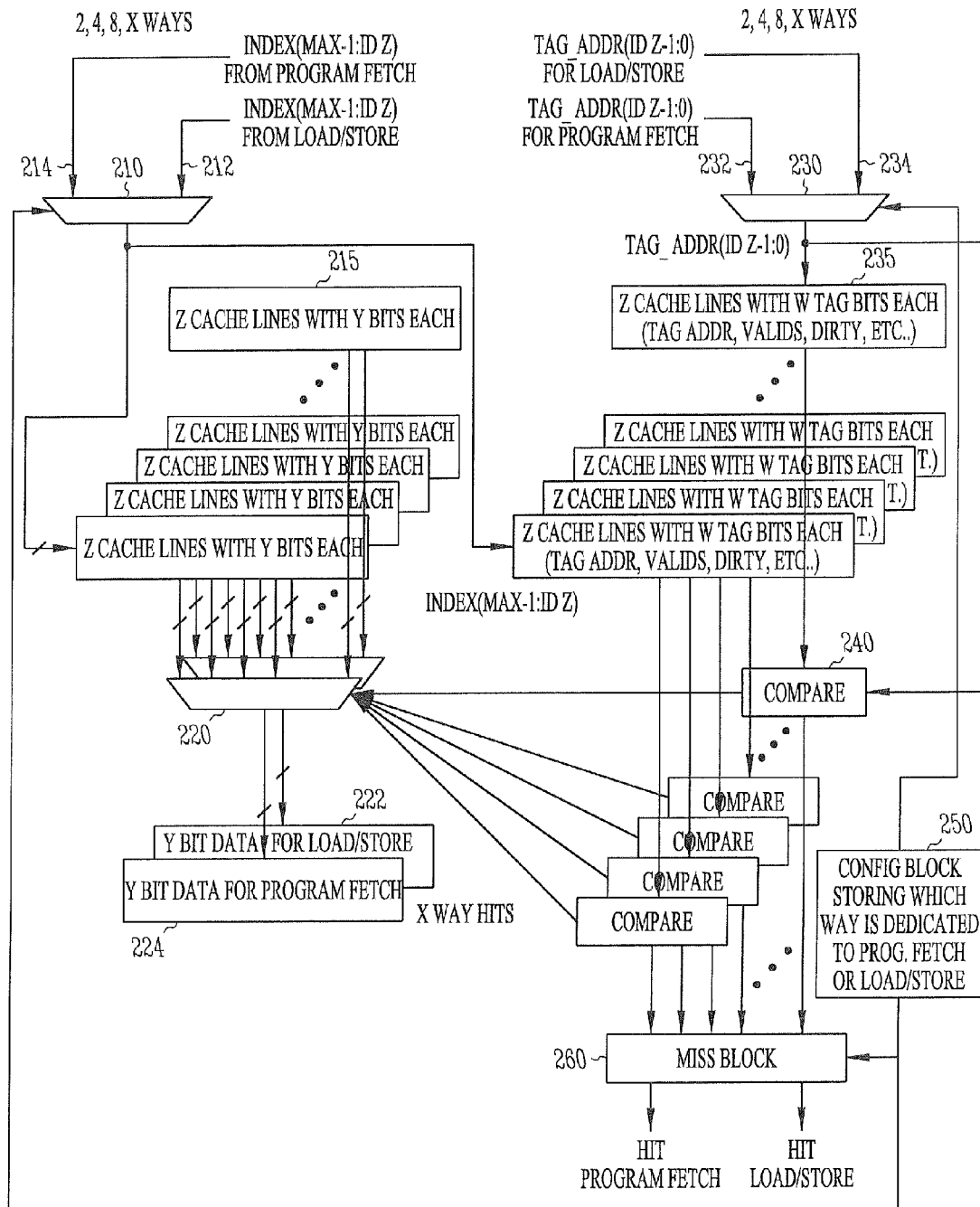
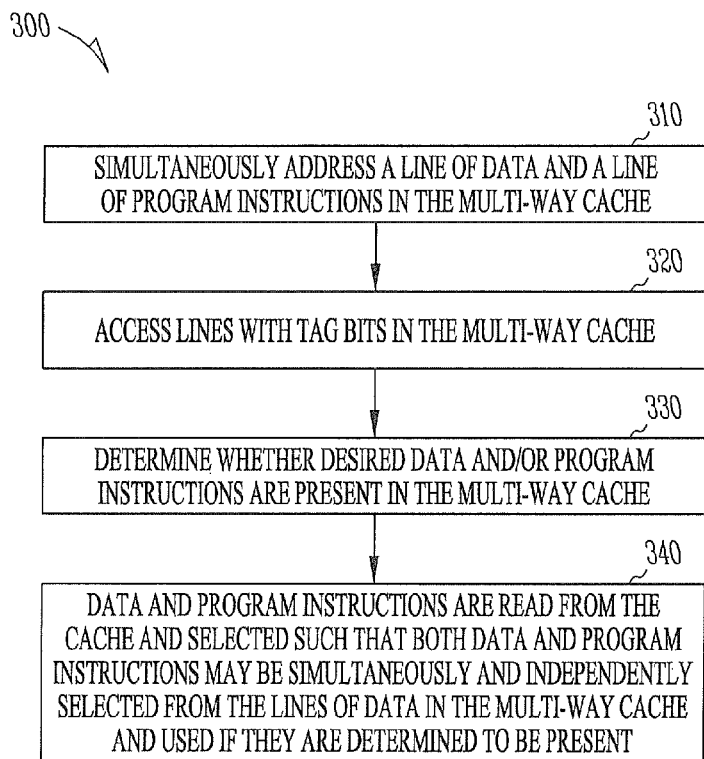
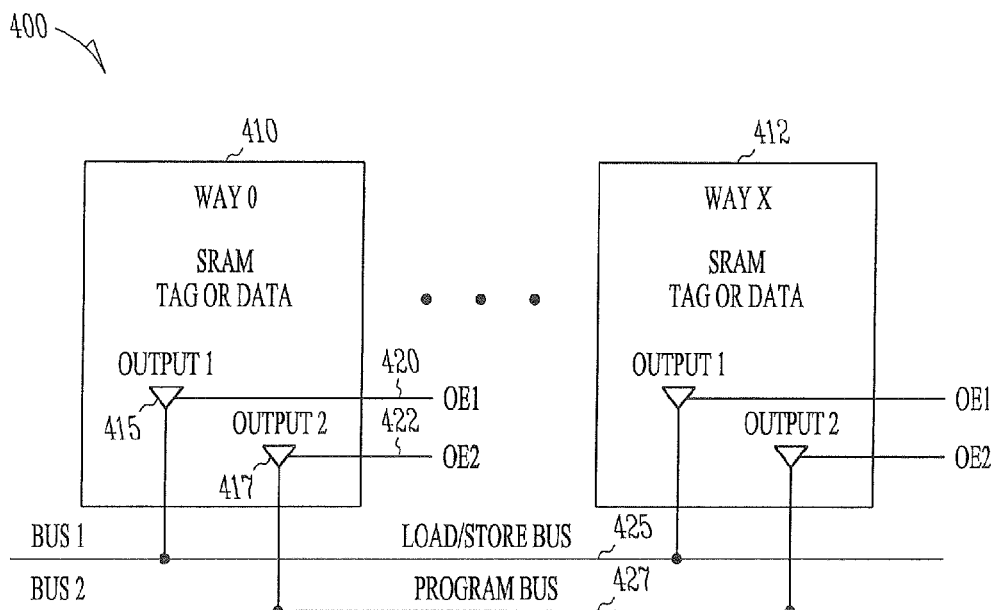


FIG. 2

*FIG. 3**FIG. 4*

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/561,494 filed Nov. 20, 2006, the contents of which are herein incorporated by reference in their entirety.

BACKGROUND

Caching of data in close vicinity of a processing core is a common approach of speeding up the performance of the microprocessor or other processing system. The cache may be a small memory that keeps data and/or instructions that were recently or often used. By keeping the data and/or instructions close to the processing unit, the latency of access is small, and overall processing speed may be increased versus accessing a larger system memory directly, which may have a higher latency of access.

There are multiple known approaches to caching for microprocessor systems. Many systems use separated data and program caches. This approach tends to be inflexible, as each cache is dedicated to either data or programs. Since applications may vary in the ratio of each required for efficient operation, separated data and program caches may not be optimized for different applications, and in fact tend to be larger than needed for many applications to ensure all applications run fast. Separate caches also imply twice the control overhead, and duplicates memory-periphery overhead, such as internal control, wordline decoders and sense amps.

In order to keep chip area used by the cache as small as possible, many systems use combined data and program caches which tend to be more flexible as they can be used by both data and program sides of the microprocessor. Many systems also allow for dedication of certain ways of a multiple way cache to either cache the instructions for a program fetch unit or the data for a load/store unit. This dedication is needed to prevent constant replacement of timing critical cached code portions by accessing data that are scattered in the memory and hence have a low hit rate. In such systems, the user can individually, such as through software, determine the exact division of the cache portions to the individual microprocessor sub units—(load store vs. fetch unit). Performance may be poor in such systems as data and program accesses may be attempted simultaneously and in parallel, but the cache can only serve one access at a time. Thus, the bandwidth is only about one-half that of using separate caches. Using dual ported SRAMs requires much larger areas, and consumes more power. Such SRAMs would also create many difficult potential corner cases, which have to be solved by surrounding control logic.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustrating a system for accessing a single port cache simultaneously for both data and program instructions according to an example embodiment.

FIG. 2 is a block schematic diagram of a system for accessing a single port cache simultaneously for both data and program instructions according to an example embodiment.

FIG. 3 is a flowchart illustrating a method for accessing a single port cache simultaneously for both data and program instructions according to an example embodiment.

FIG. 4 is a block schematic diagram of an alternative arrangement to multiplexers in FIG. 2.

In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

A single ported cache is used to simultaneously provide data and instructions to a system in one embodiment. The system has simultaneous program fetches and data load/store accesses under the premise of using only single ported memories. Selected hardware surrounding the single ported cache is duplicated to allow basically the full bandwidth for simultaneous program and data accesses to be exploited provided there is way dedication for load/store and program data, while not adding significant area and not requiring dual ported memory or separated caches. The word “simultaneous” as used herein refers to the ability of the cache to provide data during a single fetch cycle, and need not be interpreted to mean that events should be occurring at exactly the same time. In some embodiments, the accesses may occur at approximately or substantially the same time.

FIG. 1 illustrates a system 100 that includes a processor 110. In one embodiment, the processor 110 may be a microprocessor, or any other type of processor that processes data in accordance with program instructions. Processor 110 has or is coupled to a memory controller 115. Memory controller 115 may include a program fetch unit and a data load/store unit that provides addresses for accessing programs and data in a single port cache 120. In some embodiments, further circuitry as shown below may be used to multiplex addressing of the cache 120, and determine whether requested information is within the cache. In some embodiments, such circuitry may be part of the memory controller or otherwise coupled to it and the cache.

An access of information in the cache may include access of both data and program instructions at the same time. The cache is a multi-way cache in one embodiment, with information from multiple sets of data in the ways being provided with each access of the cache. A pair of multiplexers 125, one for data and one for program instructions is used to separate out information received from the cache, such that both requested data and program instructions are output simultaneously. The data and program instructions may be stored at various memory or storage devices 130 and 135 for which the cache 120 provides faster access.

In Further embodiments, SRAMs with Tristate outputs may be used. The tristated outputs may be wired together the output enables controlled accordingly to allow only one SRAM to drive its data. A multiplexer may be implemented in multiple ways e.g. transfer gates, and/or solution, etc.) In a yet a further embodiment, two tristated outputs may be added to a memory and controlled individually.

In one embodiment, the bandwidth of the cache 120 is effectively doubled. In one embodiment, at least a 2-way cache is used. For further flexibility in utilizing more of the cache for data or program instructions, 4-way, 8-way or higher, such as 32-way caches may be used. Non powers of 2 may also be used, such as a 6-way cache. Thus, more ways may be allocated to data if an application is data intensive.

The allocation of the ways to load/store or instruction may be reprogrammed for each application if desired without a redesign of the system architecture.

FIG. 2 at **200**, further detail of a system providing simultaneous access of data and program instructions from a single port cache is shown. An index address multiplexer **210** receives an index portion of two addresses from the processor. While only one is shown, it is done for each way. The addresses in one embodiment are referred to as an index, one for a load or store of data at **212** and the other for a program instruction fetch at **214**. The indexes, including a tag portion, are applied to a multiple way cache **215**, which is shown as containing *Z* lines of data with *y* bits in each line, and *Z* lines of program instructions, with *y* bits in each line. The two different types of lines, data and program instructions, are respectively coupled to a pair of output multiplexers at **220**, providing *y* bit data for load/store at **222** and *y* bit program instruction fetches at **224**.

Since a cache may or may not contain the requested information, a mechanism for checking is also provided. Portions of the addresses used to access the cache also include tag address bits. Tag address bits are provided to a tag address multiplexer **230** which while only one is shown, exists for each way. Both tag address bits for program instruction fetch at **232** and data load/store **234** are provided to multiplexer **230**. These bits are multiplexed and provided to a tag bit cache section **235**, along with the multiplexed address per way from multiplexer **210**. Tag bit cache section **235** includes *Z* lines with *w* tag bits each—tag address, valids, dirty, etc. They are further provided to multiple comparators **240**, one for each way. Comparators **240** compare the tag address bits from the processor attempting to access the cache, to those stored in the cache to determine whether the information, be it data or program instructions, is currently stored in the cache **215**. The comparators **240** are coupled to the output multiplexers **220** to control them to provide the data and instructions that are actually stored in the cache **215**. A miss or no hit indication is provided if the data and/or instructions at **222** and **224** should be ignored. The comparators have two outputs and control both load/store and program independently in one embodiment. The control affect the multiplexer **220** and the hit logic **260**. Other logic that is capable of comparing information and providing corresponding control may be used in place of the comparators if desired. Similarly, many different cache hit or miss algorithms may be employed.

A configuration block **250** provides cache configuration control to the multiplexers **210** and **230** to identify which sets of information and tag bits in the cache **215**, **235** correspond to data and which correspond to program instructions. Configuration block **250** and comparators **240** are also coupled to a cache hit or miss block **260** to ensure that results are ignored if the tag bits did not identify a cache hit. Control of multiplexers **220** is also influenced accordingly by configuration block **250**. There are 2 outputs of each comparator to the multiplexers **220** and only one output of the comparators is allowed to be activated by a hit as the other one is dedicated to another type of data.

In one embodiment, stall cycles and wait cycles in the processor **110**, such as a microprocessor, due to collisions in the cache may be prevented. This is done by duplicating the address paths of each data/tag array of each way, which allows selection if the way should be controlled by the address of the load/store or program fetch units. Additionally, the control unit, which is also responsible for translating the way hit to the data multiplexer signals takes into account which way is enabled for load/store and program fetch and controls the two data multiplexers accordingly and indepen-

dently of each other. Additionally, two hit signals are generated by the control logic, one for the load/store and one from the program fetch unit, again taking the way dedication to load/store and program fetch units into account. Additionally the control logic makes sure, that in a case where two misses happen simultaneously, one miss in the load/store access and one on the program fetch access, the necessary refills and possibly necessary write back are done sequentially. Such cache misses may be handled in a known manner.

A typical embodiment has at least 4 or 8 ways, while two will work, but not provide flexibility in assigning varying cache portions. Other numbers of ways, such as 5, 6 or 7 are also possible. A data bus may have a width of 16, 32 or 64 bits for a data portion of the cache and approximately 64 or 128, or even 256 lines in each way. The number of lines per way may be much larger or smaller in various embodiments. Each cache line may typically be a multiple of the data bus width, such as 4×64 bits. For example, one cache line (characterized by one entry in the tag array) may have 4 lines worth of data in the data portion assigned to it. In such a case, the lower bits of the address define which part of the cache line is to be read and the upper address bits decide which index. The same index selects the tag entry in the tag arrays which only exists once per cache line in one embodiment. The tag entry contains the address tags, typically about 20 bits wide, depending on the number of cache lines and address bus width of the processor. In one embodiment, the address space may be addressed by an address bus width of 32 bits, or higher in future embodiments. Additionally the tag stores information about the status of the cache line, such as if it is dirty and/or valid. The tag may also contain parity bits of the tag portion and the parities for the data portions. Parity bits for data may alternatively be stored with the data. Parity and error correction bits may be used if desired, but are not required.

In further embodiments, the system **200** may include multiple other caches, as well as random access main memory, removable storage and non-removable storage. System **200** may include or have access to a computing environment that includes input, output, and a communication connection. The system may operate in a networked environment using a communication connection to connect to one or more remote computers. The remote computer may include a personal computer (PC), server, router, network PC, a peer device or other common network node, or the like. The communication connection may include a Local Area Network (LAN), a Wide Area Network (WAN) or other networks.

FIG. 3 is a flowchart illustrating a method **300** of simultaneous access of a multi-way cache, which is single ported. At **310**, the method simultaneously addresses a way or set of data and a way or set of program instructions in the multi-way cache. At **320**, sets with tag bits are also accessed in the multi-way cache. The method then determines at **330** whether desired data and/or program instructions are present in the multi-way cache. At **340**, data and program instructions read from the cache are selected such that both data and program instructions are selected from the sets of data in the multi-way cache provided they are determined to be present.

In a further embodiment as illustrated at **400** in FIG. 4, multiple busses may be used as an alternative to multiplexers. An SRAM has multiple ways as represented by way **0** at **410** to way *x* at **412**. Each way has a first output OUT1 **415** and a second output OUT 2 at **417**. The outputs are enabled at corresponding output enable OE1 at **420** and OE2 at **422**. The outputs are coupled to a load/store bus **425** and a program bus **427**. The busses perform similarly to output multiplexers in this embodiment.

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The Abstract is provided to comply with 37 C.F.R. §1.72(b) to allow the reader to quickly ascertain the nature and gist of the technical disclosure. The Abstract is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

The invention claimed is:

1. A system for accessing a multi-way cache formed of single port memory, the system comprising:

an address multiplexer that simultaneously addresses a line of data and a line of program instructions in the multi-way cache;

a first duplicate output way multiplexer configured to select data read from the multi-way cache without selecting program instructions; and

a second duplicate output way multiplexer configured to select program instructions read from the multi-way cache without selecting data.

2. The system of claim 1, wherein the multi-way cache is a single port multi-way cache having a variable number of ways that are dedicated to data and other ways that are dedicated to program instructions.

3. The system of claim 1, wherein the multi-way cache is a single port multi-way cache and two accesses are interleaved in the single port multi-way cache.

4. The system of claim 1, wherein the multi-way cache is at least a 2-way, 4-way, 6-way, or 8-way cache.

5. The system of claim 1, further comprising:
means for determining whether requested data and program instructions are present in the multi-way cache.

6. A system for accessing a multi-way cache, the system comprising:

means for simultaneously addressing a line of data and a line of program instructions in the multi-way cache;

means for accessing lines with tag bits in the multi-way cache;

means for determining whether desired data and/or program instructions are present in the multi-way cache; and

means for selecting data and program instructions read from the multi-way cache, provided they are determined to be present, so as to provide data read from the multi-way cache to a first output without providing program instructions and so as to provide program instructions read from the multi-way cache to a second output without providing data.

7. The system of claim 6, wherein the multi-way cache is a single port multi-way cache having a variable number of ways are dedicated to data and other ways are dedicated to program instructions.

8. The system of claim 6, wherein the multi-way cache is a single port multi-way cache and two accesses are interleaved in the single port multi-way cache during a same cycle.

9. A method for accessing a single port multi-way cache, the method comprising:

simultaneously addressing a line of data and a line of program instructions in the multi-way cache;

accessing sets with tag bits in the multi-way cache;

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determining whether desired data and/or program instructions are present in the multi-way cache; and

providing data from the multi-way cache

to a first duplicate output multiplexer without providing program instructions to the first duplicate output multiplexer; and

providing program instructions read from the multi-way cache to a second duplicate output multiplexer without providing data to the second duplicate output multiplexer.

10. The method of claim 9 and further comprising identifying ways dedicated to data and ways dedicated to program instructions.

11. The method of claim 10 and further comprising providing hit indications for both a program instruction fetch and a data load/store.

12. The method of claim 9 wherein a variable number of ways are dedicated to data and other ways are dedicated to program instructions.

13. The system of claim 1, where the address multiplexer addresses the line of data and the line of program instructions at the same time.

14. The system of claim 6, where the means for simultaneously addressing a line of data and a line of program instructions in the multi-way cache addresses the line of data and the line of program instructions at the same time.

15. The method of claim 9, where the line of data and the line of program instructions are addressed at the same time.

16. The system of claim 1, further comprising:

a configuration block configured to provide a cache configuration control to an input of the address multiplexer to identify which information in the multi-way cache corresponds to data and which corresponds to program instructions.

17. The system of claim 1, further comprising:

a tag address multiplexer configured to receive tag address bits, to multiplex the tag address bits, and to provide the multiplexed tag address bits to a tag bit cache section; and

comparators configured to compare tag address bits from a processor attempting to access the multi-way cache to the tag address bits stored in the tag bit cache section and to control operation of the first and second output way multiplexers based upon the comparison.

18. The system of claim 17, wherein the tag bit cache section is configured to further receive data and program instructions output from the address multiplexer.

19. The system of claim 6, wherein the means for selecting data and program instructions, comprises:

a first duplicate output way multiplexer configured to receive data from the multi-way cache without receiving program instructions; and

a second duplicate output way multiplexer configured to receive program instructions from the multi-way cache without receiving data.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,146,874 B2
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DATED : September 29, 2015
INVENTOR(S) : Klaus Oberlaender

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

Column 6, Claim 9, Line 7 Please replace "...program instructions road from the..." with
--...program instructions from the...--

Signed and Sealed this
Twenty-first Day of June, 2016

A handwritten signature in black ink, reading "Michelle K. Lee". The signature is written in a cursive, flowing style.

Michelle K. Lee
Director of the United States Patent and Trademark Office